Original article

Textural modification of soya bean/corn extrudates as affected by moisture content, screw speed and soya bean concentration

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Summary A Clextral BP-10 (type BC45) co-rotating twin-screw extruder was used for texture modification of extrudates. Dry materials were mixed in a mixer for 15 min at low speed before extrusion. Moisture content 21–23% and addition of soya bean flour (0–40%) showed significant influences on the texture of the extrudates. Addition of soya bean flour in the range from 0 to 40% increased the diametrical expansion ratio ($P < 0.01$), decreased the hardness ($P < 0.01$) and modifies specific volume and chewing behaviours of the extrudates. Increasing moisture content in the range from 21 to 23%, however, significantly decreased specific volume ($P < 0.01$), and increases hardness ($P < 0.01$) of the extrudates. The hardness and crispness of the extrudates at fracturability of 110 g were graded higher than 6.0 by 30 and 27 of 34 consumer panelists, respectively. Consumer purchase intent showed the highest score of 5.5 in a 9-point hedonic scale when sample fracturability was at 110 g.

Keywords Corn meal, extrusion, moisture content, soya bean flour, texture modification.

Introduction

The USA is the biggest producer of soya bean in the world. The national production was 65.81 million metric tons, which accounts for 34% of the world total soya bean production, in 2003 (American Soybean Association, 2004). Protein content in soya bean seeds is approximately 40% varying with varieties and growing conditions (Liu, 1997). The high concentration of protein in soya bean seeds provides human beings an efficient source for diet protein supply. Furthermore, the amino acids of soya bean proteins are better balanced than most other plant proteins with a comparison with the daily amino acid requirement for good health recommended by FAO/WHO/UNO (1985).

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Soya bean proteins and other components have been reported effective in preventing and treating some chronic diseases (Sugiyama *et al.*, 1997). Similar with buckwheat proteins (Li & Zhang, 2001), soya bean proteins are effective in lowering serum cholesterol levels when tested on animals and human beings. Other nutraceutical components, like isoflavones, in soya bean seeds are reported biologically active in treating some chronic cardiovascular diseases, such as atherosclerosis (Reynolds, 1987). Soya bean phytosterols and soya bean lecithin are also reported having nutraceutical functionalities (Leblabc *et al.*, 1998). These findings suggest that soya bean can provide consumers health benefits after digestion. Approved by FDA in October 1999 (Henkel, 2000), following health benefit claims can be labelled on soya bean and soya bean containing foods: soya bean reduces risk of coronary heart disease. Food marketers can now use the following claim, or a reasonable variation, on their products: 'Diets low in saturated fat and cholesterol that includes 25 g of soy protein a day may reduce the risk of heart disease. One serving of (name of food) provides – grams of soy protein'. Other potential future claims may include: soy fights cancer, inhibits cardiovascular disease, reduces symptoms of menopause, lowers cholesterol and blood lipids, promotes good health, contains isoflavones, and phytochemicals which promote good health.

Extrusion was first reported for making edible full-fat soy flour in the 1960s (Mustakas *et al.*, 1964). Many research results about the influences of extrusion on the nutritional properties, flavour profile and retention, and complementary effects of soya bean/rice or soya bean/corn mixture were reported previously (Bookwalter *et al.*, 1971; Kollengode *et al.*, 1996; Leblabc *et al.*, 1998). Extrusion cooked soya bean products have been used to improve the nutritional quality, acceptability and stability of corn based foods (Bookwalter, 1977) and bread (Harper & Jansen, 1981). Although extrusion is not a non-thermal process, such as pulsed electric fields that has been reported with minimized impact on heat labile compound, i.e. bovine immunoglobulin G (Li *et al.*, 2003), the short retention time and high temperature in barrel help minimize the risk of adversary thermal influences on nutritional value of the products. Extrusion is effective in inactivating lipoxygenase, which is responsible for the formation of beany flavour in a soya bean-containing product (Mustakas *et al.*, 1969). The off-flavour development in soya bean and soya bean products is highly dependent on the action of the various endogenous lipoxygenase and the subsequent decomposition of the resultant hydroperoxide (Schwimmer, 1981; Zhu *et al.*, 1996). The inactivation of lipoxygenase in turn prevents the formation of the beany flavour in the extrudates during the storage.

The addition of soya bean flour in the formula may change the texture and overall consumer acceptance of the extrudates. Water-binding capacity of plant proteins varies with different varieties, from soya bean (Liu, 1997) to Tung cake (Li & Yang, 1995) and corn (Zayas, 1994). Addition of soya bean proteins into the extrusion mix changes the water-binding capacity of the mix. To maintain similar rheological properties of the extrusion mix and to achieve a high quality extrudate, moisture content (MC) and the extrusion parameters need to be adjusted accordingly. Nevertheless, how extrusion conditions and composition of extrusion mix affect the textures of extrudates, the correlation between extrudate properties and addition of soya bean, and how consumers' response to the modified products are still not clear. The purposes of this study are to investigate the influences of soya bean flour and extrusion conditions on the textural properties of the extrudates and to identify the correlation between instrumental fracturability and product textural acceptance by human beings. In this paper, the influences of addition of soya bean flour and variation of MC on the texture properties of the extrudates will be discussed. The optimization of extrusion conditions upon the changes in the extrusion mixture formula will also be discussed. Consumer acceptance of textures of the extrudates is illustrated in a hedonic scale sensory test with 34 participants.

Materials and methodology

Materials

Yellow corn flour

The corn meal flour used in these experiments was bought from Lauhoff Grain Company (Newman, IL, USA) and the measured MC was 7.6% (w.b.) with a protein content of 7.2%, a lipid content of 3.86% and an ash content of 1.45%.

Dehulled soya bean flour

The soya bean flour used in the investigation was bought from Archer Daniels Midland Co. (Decatur, IL, USA) and the measured MC was 6.3% (w.b.) with a protein content of about 40%, a lipid content of 20.65% and an ash content of 4.46%.

Extruder

The extruder used for the experiments was a co-rotating, twin-screw extruder (Clextral BP10; type BC45 Clextral, Firming, France) with a round die (0.3175 cm in opening diameter). There were four temperature zones with separated temperature control devices in the barrel. The temperature profile in the four sections along the barrel from dry mix feeding port to die was T_1 24, T_2 110, T_3 127 and T_4 150 °C. The ratio of the length to diameter of the two screws was 19.1 with a length of 109.22 cm. The pre-mixed material was fed directly into the feeding zone at 45.1 kg h^{-1} through the feed hopper with two co-rotating feeding screws. Water was added to the mixture using a build-in piston pump by directly injecting water into the extrusion mixture in the section 1 in the barrel. The distance of the water injection port from the dry mix feeding port was 5.1 cm. The amount of water added was adjusted by changing the running speed of the piston pump, which was calibrated prior to each run to ensure the amount of water injected was accurate. A four-blade cutter operating at 100 rpm was used at the die exit to cut the extrudates.

Methods

Procedure

The soya bean flour and corn meal were weighed separately and mixed together in a Hobart® mixer (CA-2-FD) (The Hobart MFG. Co., Troy, Oh, USA) at low speed for 15 min. After turning on the extruder and the extruder barrel was heated to the desired temperature profile, water was injected first and then the premix was introduced. The extruder operating parameters [dry mix rate, water injection rate, and screw speed (SS)] were gradually adjusted to the desired levels. When the extruder conditions were stabilized, an additional 5 min was allowed to elapse before collecting samples. The samples were dried at 45~55 °C for 30 min in an oven to achieve a final MC of 4.87 ± 0.12% and stored in plastic-loc bags at room temperature for further analyses.

Measurement of the hardness and fracturability

The hardness of the samples was measured with a TA-XT2 Texture Analyzer using a Warner Bratzler shear probe (Texture Technologies Corp., New York, NY, USA). The parameters used for operation of the TA-XT2 texture analyser were summarized in Table 1. The higher the value of the maximum peak force required in gram, which means the more force required to breakdown the sample, the higher the hardness of the sample to crackdown. The fracturability (in grams) of the extrudates was the first peak force measured accompanying the first local crackdown. Crispness of a product can be closely predicted by measurements of fracturability using texture analysers (Ocon *et al.*, 1995; Charles *et al.*, 2001). The lower the force measured at first crackdown, the higher the fracturability and crispness of the products. All the tests were repeated for five times and means and standard deviations were reported accordingly.

Table 1 TPA test conditions used for texture analysis of the extrudates with TA-XT2 texture analyser

Pre-test speed	1.5 mm:s
Test speed	2.0 mm:s
Post-test speed	10.0 mm:s
Distance	30 mm
Trigger type	Button
Data acquisition rate	400pps
Option	Return to start

Measurement of moisture content

Infrared moisture balance (CSC Scientific Company, Inc., Fairfax, VA, USA) was used to measure the MC in the samples. Temperature was set at 105 °C at auto mode. Results are the averages of the three replications.

Measurement of the expansion ratio

Ratio of the cross-sectional area of the extrudate to the cross-section area of the die is referred as expansion ratio (ER). It is the square ratio of the extrudate diameter and the die opening diameter. Because the extrudates from these experiments were all cylinders, we simplified this definition as 'Ratio of the equivalent diameter of the extrudate to that of the die'. Sixteen replications were measured for each sample and the means were reported as the ER results.

Assay of the specific volume

Specific volume (SPV) of the samples was determined by millet displacement method modified from Penfield's method with rapeseed (Penfield & Griswold, 1979). A tin can, which had a total volume capacity of 694.75 cm^3 measured with water at 4 °C, was used. About one-fourth of the can height was filled with millet. Then 10 g of extrudate was weighed with a digital balance (AB204-S; Mettler-Toledo, Inc., Greifensee, Switzerland) and then added on the top of the millet layer in the tin can. Enough millet was then added to fully fill the can container. The excess was scraped out with a stainless steel strip to make sure the total filling volume of the containing is as close to the actual volume capacity (with water) of the can as possible. The SPV of the sample was then calculated according to the following equation:

$$\mathrm{SPV} = (694.75 * \rho - w_2 + w_1 + w_0) : (w_1 * \rho) \quad (1)$$

where ρ refers to the density of the millet, w_1 refers to the weight of extrudate sample in grams, w_2 refers to the total weight of the filled can container and w_0 refers to the weight of the empty tin can.

Consumer acceptance of the hardness and crispness of the samples

A consumer panel (34 members involved) was used to evaluate the suitability of the crispness and hardness of the extrudates. Before tests, the panelists were trained using a series of commercially available cheese curls and corn extrudates to anchor the perception of the hardness and crispness of extruded snack products. Standards used for anchoring sample hardness were cream (1), olives (4) and rock candy (9) in 1–9 scale. The purchasing intention was anchored using commercially available corn puffs in 180 g (6 oz) plastic bags that ranged from 0.99 to 1.54, and the panelists were told only to compare the appearance, hardness and crispness of the samples, regardless the smell and taste. The panelists were asked to grade the acceptance of the hardness and crispness in a 9-point hedonic scale. The answer sheets were collected and the data were analysed statistically. The sensory results were compared and graphed against the instrumental measurements of hardness and fracturability of the samples.

Design of the experiments

A 4 (soya bean:corn ratio) × 3 (SS) × 3 (MC) × 2 (replication) factorial design was used to investigate the importance of the influences of addition of soya bean, SS and MC on the texture of the extrudates. The design combination was shown in Table 2.

Statistical analysis

Data were analysed using the analysis of variance (ANOVA) and Regression Analysis (REG) procedure of the Statistical Analysis System (SAS) for Windows V.801 (SAS Institute Inc., 1999). All significance testing was conducted at the 0.01% significant level except otherwise specified.

Table 2 Factors and levels investigated for the 4 × 3 × 3 × 2 factorial experimental design*

Factors	Soya bean (%)**	Screw speed (rpm)	Moisture content (%)	Replication
Levels				
1	0	200	21	1
2	15	275	22	2
3	30	350	23	
4	40			

*Samples were nominated by the combination of the numbers that represent the four factors and their levels. For instance, sample 3312 referred to the sample processed using soya bean (%) of 30% in the dry mixture (soya bean:corn ratio of 30:70), screw speed of 350 rpm, moisture content of 21% and replication 2.

**Soya bean (%) refers to soya bean concentration or soya bean addition level in the dry mix of dehulled soya bean flour and yellow corn flour.

Results and discussion

Specific volume of the extrudates

The influences of soya bean addition, SS and MC in the raw mix on the SPV of the extrudates are illustrated in Fig. 1. Higher SS, lower MC and higher soya bean addition resulted in higher SPV in the investigated ranges. The three parameters had significant interaction with one another. Unlike MC and SS, the addition level of soya bean flour in the mix showed a different effect at low dosage with that at high dosage.

The statistically analytical results for SPV from SAS analysis are summarized in Table 3. ANOVA analysis revealed that soya bean (%) ($P < 0.0001$), SS ($P < 0.0001$), MC ($P < 0.0001$) and the interaction between soya bean (%) and SS ($P < 0.0001$) all have significant influences on the SPV of the extrudates. This implies that soya bean addition level, SS and MC in the investigated range are critical for the SPV of the extrudates. Moreover, soya bean addition level and SS had significant interaction and showed significant influence on SPV of the extrudates ($P < 0.001$). Soya bean addition level and MC showed a significant interaction ($P = 0.0059$). When the soya bean addition level was increased from 0 to

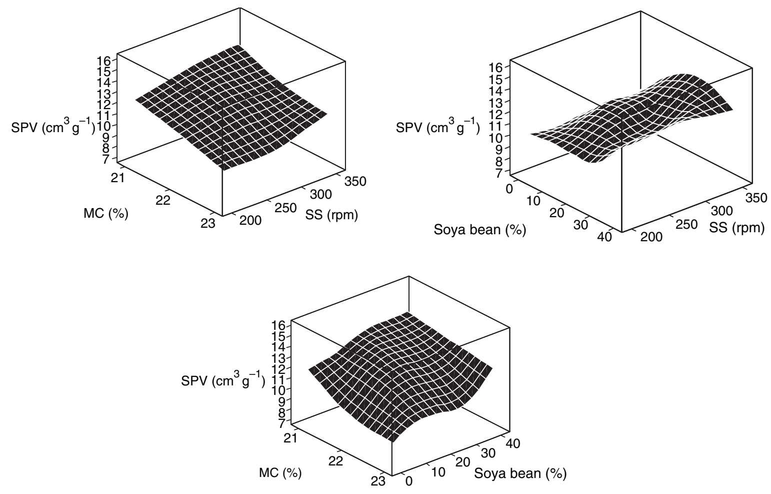

Figure 1 Influences of screw speed and addition of soya bean flour and water on SPV at a fixed feed rate of 45.1 kg h^{-1} and a barrel profile of T_1 24 °C, T_2 110 °C, T_3 127 °C and T_4 150 °C.

Table 3 Summary of the ANOVA analysis for SPV

Source	Degree of freedom	ANOVA SS	Mean square	*F*-value	Pr > *F*
Soya bean (%)	3	86.723	28.908	46.36	<0.0001
SS (rpm)	2	23.939	11.970	19.19	<0.0001
Soya bean × SS	6	35.376	5.896	9.45	<0.0001
MC (%) (wb)	2	78.038	39.019	62.57	<0.0001
Soya bean × MC	6	13.874	2.312	3.71	0.0059
SS × MC	4	4.068	1.017	1.63	0.1883
Soya bean × SS × MC	12	8.834	0.736	1.18	0.3340
REP	1	0.1112	0.1112	0.18	0.6754

40%, to achieve a same level of SPV of the extrudates, MC needed to be increased accordingly. However, MC and SS did not show significant interaction in the investigated range ($P = 0.1883$).

The relationship between the SPV of the extrudates and soya bean content, MC, SS and their interactions was expressed in eqn 2, which was regressed by SAS statistic software:

$$\begin{aligned}\mathrm{SPV}(\mathrm{cm}^3:\mathrm{g}) = {} & -0.19920 \times \text{soya bean} + 0.01005 \times \mathrm{SS} \\ & - 1.54474 \times \mathrm{MC} + 0.01269\ \text{soya bean} \\ & \times \mathrm{MC} + 41.60266 \qquad (2)\end{aligned}$$

where 'soya bean' represents percentage of soya bean flour added in the mixture (%).

The correlation coefficient is 0.6772 ($P < 0.0001$), which implies that the regressive equation can well describe the resultant extrudate texture due to the changes in the operational parameters and different compositions.

Effects of screw speed and addition of soya bean and water to the diametrical expansion ratio of the extrudates

Figure 2 illustrates the effects of SS, addition of soya bean and water and their interactions to the diametrical ER of the extrudates. Increase in SS causes decrease in extrudate ER. However, addition of soya bean flour in the mix showed different effects at different addition level. Addition level of soya bean flour at 15% caused significant decrease in ER when SS was in the range of 200–350 rpm and MC of 21–23%. ANOVA analysis regarding ER of the extrudates was summarized in Table 4. Soya bean concentration, SS and MC all had significant influence on ER of the extrudates when counted separately ($P < 0.0001$). Soya bean concentration and SS had significant interaction at $\alpha = 0.0001$ level. However, the interaction between SS and MC did not show significant influences on the ER even at $\alpha = 0.05$ level. No

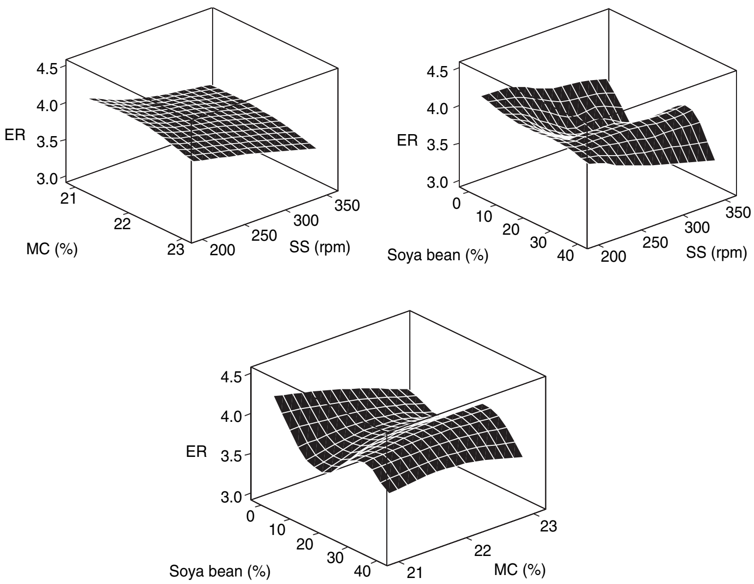

Figure 2 Effects of screw speed, addition of soya bean and water and their interactions on the diametrical expansion ratio of the extrudates when extruded at a fixed feed rate of 45.1 kg h^{-1} and a barrel profile of T_1 24 °C, T_2 110 °C, T_3 127 °C and T_4 150 °C.

Table 4 Summary of ANOVA analysis of ER changes with the modification of operation parameters

Source	Degree of freedom	ANOVA SS	Mean square	*F*-value	Pr > *F*
Soya bean (%)	3	1.718	0.573	63.4	<0.0001
SS (rpm)	2	2.255	1.127	124.78	<0.0001
Soya bean × SS	6	0.643	0.107	11.87	<0.0001
MC (%) (wb)	2	0.347	0.173	19.18	<0.0001
Soya bean × MC	6	0.659	0.110	12.15	<0.0001
SS × MC	4	0.026	0.0064	0.71	0.5910
Soya bean × SS × MC	12	0.412	0.034	3.80	0.0010
REP	1	0.0156	0.0156	1.73	0.1973

significant difference was observed between the replications ($P = 0.1973$).

The relationship between ER and the independent parameters was expressed in eqn 3 regressed with SAS software.

$$\begin{aligned} ER = 8.2240 &- 0.05814 \times \text{soya bean} \\ &- 0.0030 \times SS - 0.1593 \times MC \\ &- 0.000152 \times \text{soya bean} \times SS \\ &+ 0.00233 \times \text{soya bean} \times MC \\ &+ 0.00000731 \times \text{soya bean} \times SS \times MC \quad (3) \end{aligned}$$

where 'soya bean' represents percentage of soya bean flour added in the mixture (%).

In eqn 3, all three interactions, soya bean × SS, soya bean × MC and soya bean × MC × SS, were not significant with *P*-values of 0.7338, 0.6895 and 0.7185, respectively. So eqn 3 was again modified into eqn 4 by removing the interaction items.

$$\begin{aligned} ER = 8.2240 &- 0.05814 \times \text{soya bean} - 0.0030 \\ &\times SS - 0.1593 \times MC \quad (4) \end{aligned}$$

The analytical results for ER revealed (not listed in this paper) that the soya bean concentration level of 3, which corresponds to 30% soya bean addition (or soya bean/corn = 30:70), led to the highest ER while 200 rpm SS resulted in the highest ER among the investigated level. In terms of ER of the extrudates, 21 and 22% MC levels did not show a significant difference. However, 23% MC did show a significant difference from the other two moisture levels.

Hardness of the extrudates as affected by screw speed and the addition of soya bean flour and water

Increases in addition level of soya bean flour in the mix and increase in SS significantly decreased the

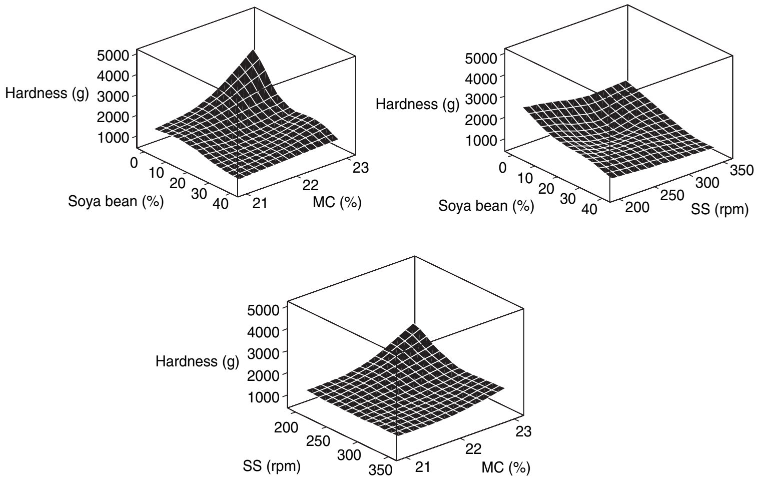

Figure 3 Influences of screw speed and addition of soya bean flour and water on hardness of the extrudates made from soya bean/corn mix when extruded at a fixed feed rate of 45.1 kg h^{-1} and a barrel profile of T_1 24 °C, T_2 110 °C, T_3 127 °C and T_4 150 °C.

hardness of the extrudates ($P < 0.001$) (Fig. 3). However, increase in MC of the mix caused increases in hardness of the extrudates. Not only the three single parameters showed significant influences on the hardness of the products, but also the interactions among them showed significant effects in determining the hardness of the extrudates. The influences of operation conditions on hardness of the extrudates were analysed with SAS software and the results were summarized in Table 5. Soya bean, SS, MC, interaction effect between SS and MC, and the interaction effect between soya bean concentration and MC had significant influences on the hardness of the extrudates at $\alpha = 0.0001$ level ($P < 0.0001$). Increasing addition level of soya bean from 0 to 40% in the mixture dramatically decreased the hardness from 2258 to 1041.8 g ($P < 0.0001$). However, increasing MC from 21 to 23% (w/b) increased hardness from 1197.4 to 1978.8 g ($P < 0.0001$). Soya bean concentration and MC show a significant interaction ($P < 0.0001$). This phenomenon strongly suggested that increasing the amount of soya bean added in the mixture required a corresponding increase in MC in order to achieve the same level of hardness.

The elevated moisture requirement may be because of the increase of protein, which needs more moisture to hydrate, in the mixture due to addition of soya bean flour, which has about 40% protein whereas corn meal flour only contains 7.6% protein. Soya bean proteins can perform as high quality emulsifiers between hydrophilic materials and hydrophobic materials by exposing the hydrophilic groups and hydrophobic groups into the corresponding phases. As a result, with a high soya bean concentration, the pores formed in the extrudates after being squeezed out of the die are smaller and more uniform than that with no or less soya bean addition. The wall thickness of the

Table 5 Influences of extrusion condition and soya bean addition on HRD analysed with SAS

Source	Degree of freedom	ANOVA SS	Mean square	*F*-value	Pr > *F*
Soya bean (%)	3	15232131.6	5077377.21	123.45	<0.0001
SS (rpm)	2	2128309.54	1064154.77	25.87	<0.0001
Soya bean × SS	6	490445.32	81740.89	1.99	0.0940
MC (%) (wb)	2	8095304.19	4047652.10	98.41	<0.0001
Soya bean × MC	6	8677262.35	1446210.39	35.16	<0.0001
SS × MC	4	2039557.94	509889.49	12.40	<0.0001
Soya bean × SS × MC	12	979104.78	81592.07	1.98	0.0571
REP	1	2110.33	2110.33	0.05	0.8221

pores gets thinner when the amount of soya bean added increases – this reflects in the hardness decrease with the increase in soya bean addition level. The influence of operation conditions on the changes of extrudates in terms of hardness in gram was expressed in eqn 5 by using Regression Analysis Procedure.

$$\begin{aligned} \text{HRD (g)} = {} & 766.9014 \times \text{soya bean} + 78.8933 \times \text{SS} \\ & + 1829.8688\text{MC} - 1.2323 \\ & \times \text{soya bean} \times \text{SS} - 3.7030 \times \text{SS} \times \text{MC} \\ & - 36.2158 \times \text{soya bean} \times \text{MC} \\ & + 0.0561 \times \text{soya bean} \times \text{SS} \times \text{MC} \\ & - 37433 \qquad (5) \end{aligned}$$

where 'soya bean' refers to the percentage soya bean in the mixture (%).

In this model MC shows a highly significant determining effect ($P < 0.0001$). SS, soya bean, interaction of soya bean and MC, interaction of SS and MC, in the investigated range, had significant influences on the anticipated hardness in grams according to eqn 5 ($P < 0.05$). However, in eqn 5, the interaction between the soya bean and SS and the interaction among soya bean, SS and the MC, ($P = 0.3434$ and $P = 0.3424$, respectively), did not show significant influences on hardness of the extrudates.

Screw speed, MC and soya bean all had significant influences on the ER ($P < 0.0001$), SPV ($P < 0.0001$) and hardness ($P < 0.0001$) of the extrudates. As shown in Figs 1 and 2, no secondary TPA area was observed. The extreme variation analysis (EVA) revealed that soya bean concentration of 40% resulted in the highest SPV and smallest breakdown force or hardness of the extrudates. However, ER at 40% soya bean level was the smallest one among the ones from all other samples. When at a soya bean concentration level of 30%, the ER was the highest and the hardness was higher only than that at a soya bean concentration level of 40%. The differences in SPV and hardness between 30 and 40% soya bean levels all were not significant. The SPV of the extrudates was as high as 12.25 $cm^3\ g^{-1}$, which was slightly higher than commercial cheese curl's 12 $cm^3\ g^{-1}$ (measured in our laboratory as the reference). Considering all SPV, hardness and ER of the extrudates comprehensively, soya bean concentration, at a level of 30%, led to the most ideal extrudate texture based on the consumer acceptance test using the trained consumer panel. Previous studies by other researchers also showed that, when whole soya bean was used, approximately seven parts by weight of cereal mixed with three parts of soya bean result in a mixture with high protein quality [protein efficiency ratio (PER), is between 2.5 and 2.6] and yielded acceptable products (Bressani *et al.*, 1974). The increase in the addition level of soya bean flour in the formula led to an increase in SPV of the extrudates and a decrease in hardness. The increase in soya bean addition level led to increase in protein content of the extrusion mixture because of soya bean's high protein content of 40% (w/w). The increased protein content in the extrusion mixture in turn required more water to let the proteins and starches completely hydrated. On the hand, increased MC higher than 21% will allow the proteins and the carbohydrates hydrate in a more complete manner and form a stronger network to resist the expansion at the exit of the die during the sudden release of pressure. The excessive increase in the resistance to the expansion led to a reduced ER and thick wall of the pores. The increased wall thickness of pores may be the reason causing increase in hardness and decrease in crispness of the samples.

Consumer acceptance and purchasing intent to the extrudate hardness and crispness

Sample 4312 (Fig. 4) had a hardness of 1300 g, which was similar with commercial cheese curl's 1600 g (Fig. 5). Sample 4312 (120 g) was crispier than commercial cheese curl (160 g). Sample 4312 was selected to investigate the consumer acceptance of the hardness and the crispness of the extrudates and purchasing intent for the products. The panel evaluation of the extrudate sample for the suitability of the crispness and hardness led to the results as described in Figs 6 and 7. Figure 6 illustrates the consumer acceptance of the crispness of the extrudates. The crispiest sample at fracturability of about 60 g did not receive the highest consumer acceptance. Interestingly, the highest consumer acceptance occurred at fracturability of about 110 g. The panelists showed only low purchasing intention (2 in a 9-point scale) to

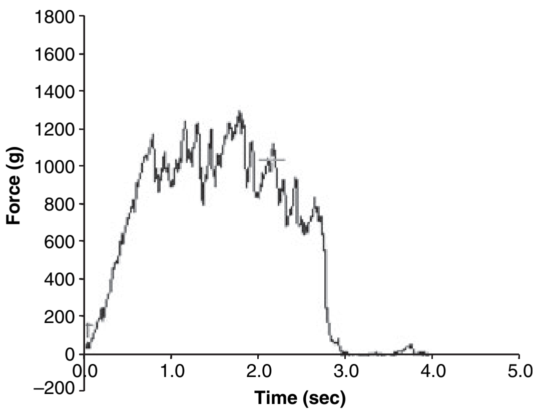

Figure 4 TPA curve of sample no. 3312 that was made from a mixture of 30% soya bean and 70% corn flour at screw speed of 350 rpm and moisture content of 21%.

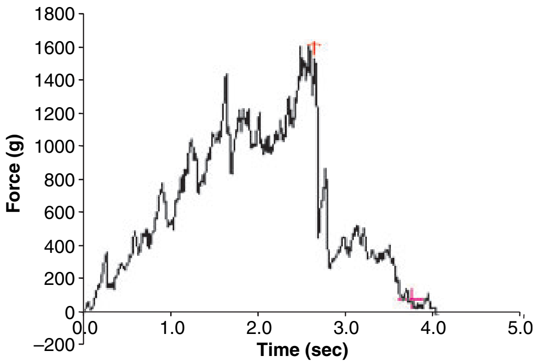

Figure 5 Typical TPA curve of commercial cheese curls.

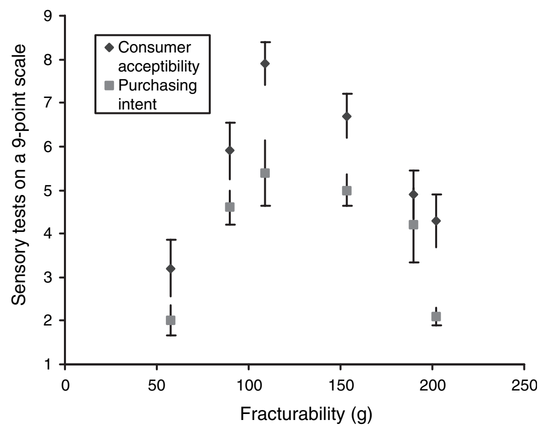

Figure 6 Consumer acceptance and purchasing intent for the extrudates with different fracturability (using a consumer panel of 34 panelists).

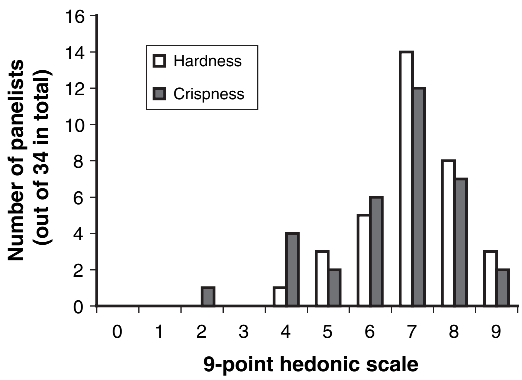

Figure 7 Consumer panel evaluation of the texture of the extrudate sample no. 3312 that was made from a dry mixture of 30% soya bean at screw speed of 350 rpm and moisture content of 21%.

an extruded snack product that had a fracturability of 60 g. Instead, manufacturers should make the extruded crispy snack foods with fracturability at about 110 g. The extrudate made from a mixture with a soya bean concentration of 30% at 350 rpm SS and 21% MC had reasonable hardness and crispness (Fig. 7), which the panelists found very acceptable. Fourteen of the 34 panelists graded the suitability of the hardness of the sample as about 7.0, 8 of 34 graded the hardness as 8.0 and 3 of the 34 panelists graded the hardness of the sample as perfect (9.0) in a 9-point hedonic scale. Twelve of the 34 panelists graded the crispness of the sample as 7.0, 7 of 34 panelists graded the crispness as 8.0 and 2 of the 34 panelists graded the sample as perfect in terms of crispness in a 9-point hedonic scale.

Conclusions

Addition of soya bean flour significantly influenced the textural properties of the extrudates made from a soya bean/corn mixture. Increase in additional soya bean level from 0 to 40% increased the SPV ($P < 0.0001$) and decreased the hardness ($P < 0.0001$) of the samples. The porous texture and crispness of the samples were improved by soya bean flour. However, addition of soya bean flour increased the moisture needed to hydrate the dry mix and form continuous film during extrusion.

Moisture content had significant influences on the textural properties of the extrudates. In the investigation range from 21 to 23%, the less the

MC in the extrusion mix, the more porous the texture and the larger the SPV of the samples. Meanwhile, the hardness of the samples decreased with the decreasing MC in this range. Moisture content at 21% showed as the optimal moisture level for the extrusion practice with a soya bean/corn ratio of 30:70 (w/w).

Consumer acceptance of the crispness of the extrudates increased with decrease in sample fracturability from 200 to 110 g, but quickly decreased when further sample fracturability decreased lower than 110 g. Fracturability of 110 g was considered as the optimal level to achieve the highest consumer acceptance (8.0 in a 9-point hedonic scale) of crispness. The consumer panel showed highest purchasing intent of the sample when the fracturability was 110 g. The hardness and crispness of the extrudates made from a mixture of 30% of soya bean and 70% of corn flour with 21% MC in the raw mix at 350 rpm SS received were graded higher than 6.0 by 30 and 27 of the 34 panelists, respectively.

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